



The 7th International Conference on Applied Energy – ICAE2015

Effects of Exhaust Gas Recirculation (EGR) on a Diesel Engine fuelled with Palm-Biodiesel

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Abstract

Increasing global population in present years means more vehicle ownership which leads to the increasing of oxides of nitrogen (NOx) and greenhouse gas emission. Oxides of nitrogen (NOx) are produced from the fuels which burned at high temperatures; contributes to the formation of ozone smog, harmful unseen particles, acid rain, and oxygen depletion that reduced the water quality. The use of higher oxygenated nature biodiesel as an alternative fuel also contributes to the increasing formation levels of NOx emission. In respond to the matters arise, exhaust gas recirculation (EGR) has been introduced to control NOx emissions from diesel engines effectively which lowers the oxygen concentration in the combustion chamber. In this paper, an experimental study was conducted on a Mitsubishi 4D68 four stroke, water cooled DI diesel engine fuelled with neat palm-biodiesel operating with diaphragm exhaust gas recirculation (EGR). Both biodiesel fuel and EGR are employed together to evaluate the engine performance and exhaust emission particularly NOx content. Tests were performed under a steady state condition where conventional diesel fuel was used as a baseline fuel. According to the experimental results, diesel engine operating with palm-biodiesel and EGR reduced the brake power output, decreased the engine torque, increased fuel consumption, decreased NOx and absolute slight increment in other emissions include CO₂, CO, and particulate matters.

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Peer-review under responsibility of Applied Energy Innovation Institute

Keywords: Oxides of nitrogen (NOx); exhaust gas recirculation (EGR); palm-biodiesel; engine performance and exhaust emission

1. Introduction

One of the considerable alternative renewable fuel sources is vegetable oils which have similar combustion characteristics and psychochemical properties to the petroleum diesel [2,3]. many researchers had well-documented their reports on the study of the vegetable oils on their properties and their effects to

the engine performances and exhaust emissions [4-9]. According to Knothe et al. [5], the selection of vegetable oils mainly based on geography and climate condition where such as corn, soybean, peanut, rapeseed, canola and olive mostly planted in Europe and United States, while in Asia, South America and Africa preferred for palm oil, coconut, jathropa as well as rubber seed. These vegetable oils have several advantages include low level of sulfur, higher oxygenated nature, higher cetane number and produce less toxic emission when they are burned [2]. Moreover, these crop oils have a better lubrication and a higher ignition temperature which not very flammable (LR). There were great potentials for the vegetable oils to be discovered in terms of engine performance and exhaust emission. Song et al. [10] reported that both intake oxygen enrichment and biodiesel fuel which higher oxygenated nature increase NO_x emissions. They also concluded that the increase was higher when more oxygen is used during combustion rather than oxygenated fuels were used. According to Lapuerta et al. [7], the oxygen content of biodiesel could not cause any increase in NO_x formation because the combustion flow occurs in the oxygen-fuel ratio region around the stoichiometric one, which is normally around 3.58 for a standard diesel fuel and 2.81 for typical biodiesel fuels. Exhaust gas recirculation is the effective way to control the NO_x formation; where reducing the exhaust temperature during combustion [11, 12]. Walke et al. [1] reported that there is vast reduction in NO_x emission but slight increasing in bsfc and smoke density concentration corresponding to the higher EGR rate. Rajan et al. [13] investigated the effect of biodiesel on a four stroke DI diesel engine fueled with sunflower methyl ester (SFME) employing the EGR technique. They reported that there is a reduction on 25% less NO_x emission at the same level smoke emissions with 15% EGR rate.

2. Materials and Methods

In this research, transesterification processes were used to produce biodiesel (Palm methyl ester). Unlike conventional diesel, palm-biodiesel has higher oxygen and lower sulfur but no aromatic ring in the molecule. These unique properties have proven that palm-biodiesel is more biodegradable and environmentally-safe. The pour point, flash point and viscosity of palm-biodiesel are higher than those of conventional diesel. This study was conducted in a Mitsubishi 4D68 SOHC in-line four stroke, direct injection diesel engine equipped with diaphragm type EGR. It is a water-cooled, low-speed and the maximum power was 64.9 kW at 4500 rpm. The engine was coupled to a 150 kW ECB eddy current dynamometer equipped with Dynalec controller which used to control the engine speed and torque. Two separate fuel tanks equipped with thermocouples and a fuel valve system were used, one for diesel and

the other for biodiesel. In fuel delivery system, fuel flow meter brand AIC 1204 was used to measure the fuel consumption for both fuels. EKOS 9000 Smoke Tester was used for measuring smoke density .

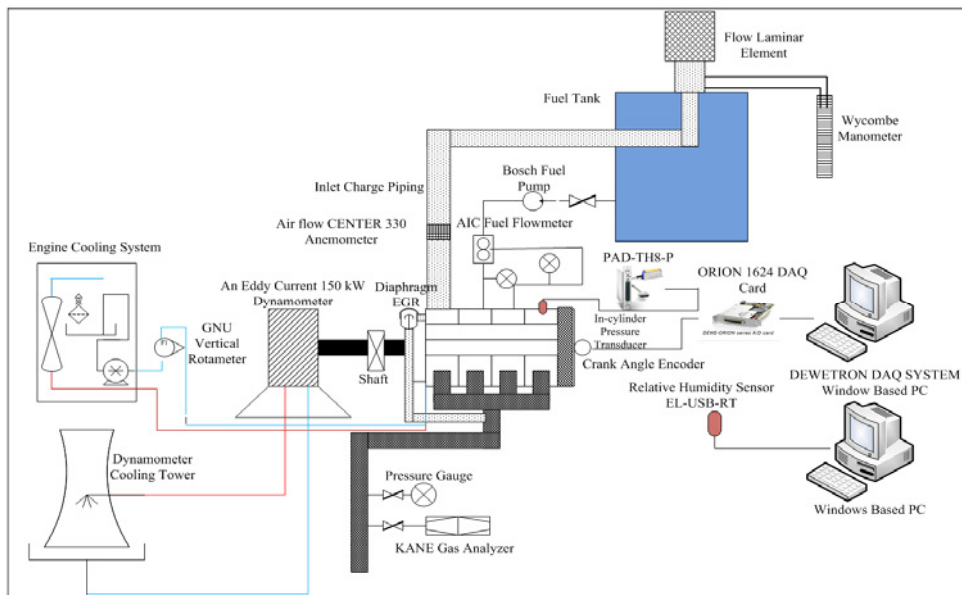


Fig. 1. Engine Testing Set up

3. Results and discussions

Engine running with palm methyl ester has lower brake power compared to conventional diesel on average 3.9% correspondingly (figure 2(a)). Lower heating value and higher density as well as higher viscosity of palm-biodiesel were found to be the major factors for the results. EGR employment on diesel engine for the fuel tests also establishes profound results. Conventional diesel with EGR has produced lower power compared to the condition without EGR with the reduction rate of nearly of 4.1% due to different combustion efficiency of the engine. This result shows that when diesel engine operating with EGR, engine power dropped rapidly due to lower oxygen burned in the chamber and leads to incomplete fuel burning as well as lower thermal efficiency. It is illustrated that the brake torque when the engine running with palm-biodiesel has decreased to average 2.8% respectively compared to conventional diesel. Again, biodiesel psychocemical properties include density and viscosity has to be blamed for the existing results. In other section, palm-biodiesel with EGR had lower torque as compared to diesel with EGR over 76.3% respectively. It was found that torque for palm-biodiesel has decreased to 5.9% correspondingly when operating with EGR at increasing engine speeds (figure 2(b)). This study also demonstrated that the loss in power and torque for the conventional diesel and palm-biodiesel fuels has been affected by the

presence of lower oxygen from the inlet charge during combustion process when operating with EGR. Lack of oxygen during combustion leads to the combustion inefficiency and incomplete burning of the fuels. Results have demonstrated that diesel had the lowest bsfc overall with those two conditions throughout the study. Increase in BSFC was understandable as palm methyl ester have approximately 2.1% less energy than conventional diesel (figure 2(c)). The higher the palm oil contents in the biodiesel, the lower its heating value.

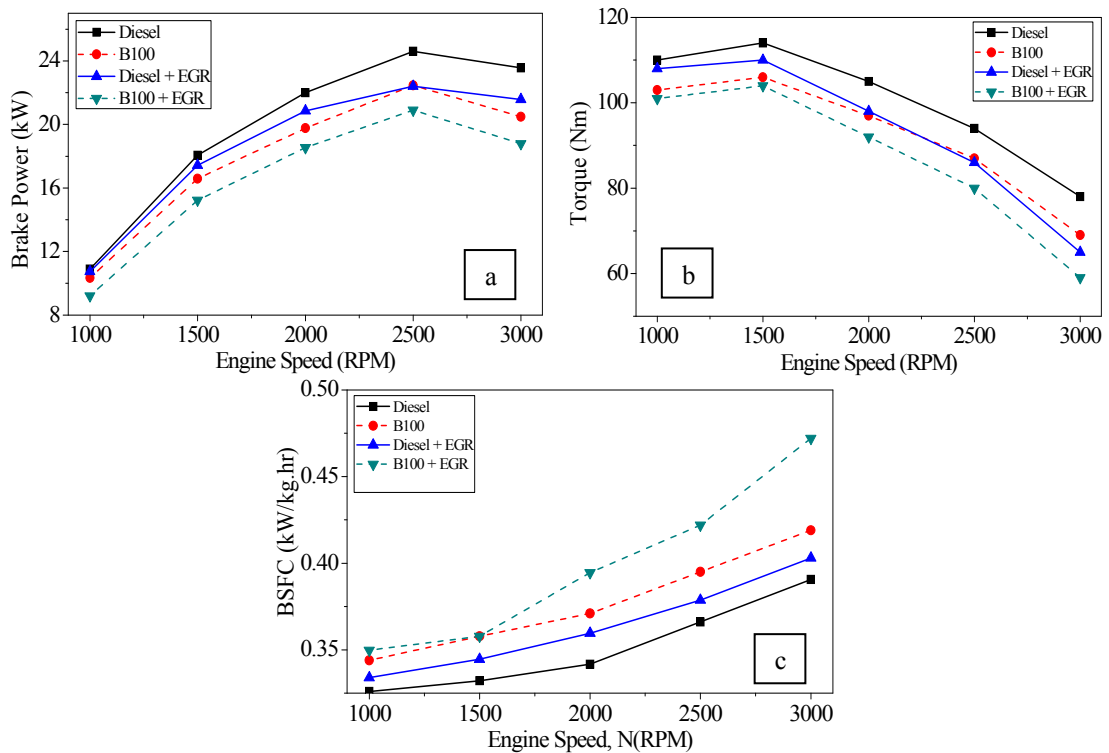


Fig. 2. (a) Engine brake power, (b) Torque and (c) BSFC corresponding on engine speeds fueled with conventional diesel and palm-biodiesel

Palm-biodiesel has higher formation levels of NO_x emission along the increasing engine speeds as compared to other working fuels; neat diesel (figure 3(a)). This mainly attributed by higher oxygenated nature content in palm-biodiesel which leads to highly-oxidized flammable in the cylinder as well as increasing the exhaust temperature and producing higher formation levels of NO_x emission. Generally the NO_x emission tends to reduce significantly with increase in EGR quantity at all the load conditions due to the rise in total heat capacity of the working gases by EGR, which lowers the elevated peak temperature. It is found that the content of NO_x emission with the increasing engine speeds is comparable less using EGR when operating with the working fuels. As comparison, percentage of CO emission for diesel fuel

has linearly increased overall 6.2% due to increasing engine speed when running with EGR (figure 3(b)). While in palm-biodiesel, it is found that CO emission has increased to a 9.2% corresponding with the increasing engine speeds under EGR mode. Percentages of CO emission from palm-biodiesel were higher than diesel when operating with EGR due to the some of the oxygen present in the inlet charge is replaced with recirculates exhaust gas that causes incomplete combustion. Furthermore, the increasing cetane number in palm-biodiesel helps to reduce the CO concentration in the exhaust piping. It was illustrated that palm-biodiesel has the highest rate emitting UHC with nearly 12% as compared to conventional diesel when operating with EGR due to the reduction of oxygen in the inlet charge, replaced by higher amount of carbon dioxide (CO_2) into the cylinder (figure 3(c)). It was demonstrated that CO_2 emission was increased when operating with the increasing engine speeds with palm-biodiesel with 9.4% under EGR mode. Result showed that mode of engine speed also has influenced the percentage of carbon dioxide adding with EGR as well as biodiesel contents. As for conventional diesel, an increasing of 7.3% for CO_2 emission when operating with EGR, while for palm-biodiesel, the percentage has increased to 6.4% correspondingly (figure 3(d)).

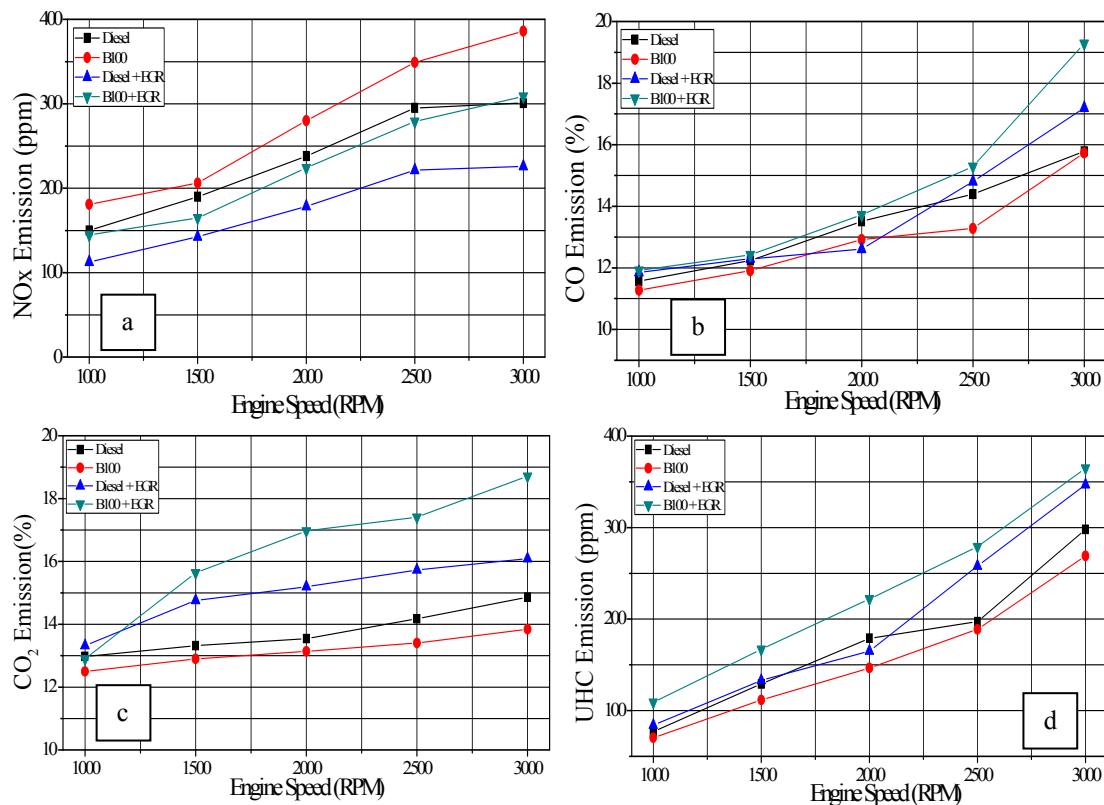


Fig. 3. (a) NOx, (b) CO, (c) CO_2 and (d) UHC corresponding on engine speeds fueled with conventional diesel and palm-biodiesel

5. Conclusions

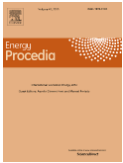
Based on the experimental test results from the engine testing, it can be concluded as follows:

- i. Both EGR and biodiesel have increased the specific fuel consumption (SFC) and reduced the engine performance of the diesel engine include engine power and torque as well as brake thermal efficiency.
- ii. Other emissions such as CO and HC also found to have decreased simultaneous with the use of biodiesel fuel.
- iii. Biodiesel has higher oxygen-natured which leads to better combustion, produced higher NOx emission in exchange.
- iv. This higher NOx emission can be effectively controlled by using EGR.
- v. EGR increases the CO and HC emissions due to incomplete combustion and reduced the exhaust temperature in advance.

In summary, engine operation fueled with palm-biodiesel while employing EGR results in NOx emission reductions without neglecting engine performance as well as exhaust emissions.

References

1. Walke DNVD PV, Bodkhe RG. Impact of Exhaust Gas Recirculation on the Performances of Diesel Engine. Proceedings of the World Congress on Engineering (WCE) 2008 London, U.K. 2008.
2. heng Sit Foon CYM, Yusof Basiron, Yung Chee Liang, Ma Ah Ngan. Palm Biodiesel: Gearing Towards Malaysian Biodiesel Standards. Malaysia Palm Oil Board (MPOB). C2005: 28-34.
3. Tsolakis AA-A J, Rodríguez-Fernández J, Megaritis A, Theinnoi K, Cracknell RF, Clark RH. Performance, combustion and emissions of a diesel engine operated with reformed EGR. Comparison of diesel and GTL fuelling, *Fuel*. 2009;**88**: 1031-41.
4. Joel Mokyr RHS. The Second Industrial Revolution, 1870-1914. 1998:1-18.
5. Knothe G, Gerpen JV, Krah J. The Biodiesel Handbook: American Oil Chemists' Society Press; 2005.
6. Atadashi IM, Aroua MK, Aziz AA. High quality biodiesel and its diesel engine application: A review. *Renewable and Sustainable Energy Reviews*. 2010;**14**:1999-2008.
7. Magin Lapuerta OA, Jose' Rodriguez-Fernandez. Effect of biodiesel fuels on diesel engine emissions. *Progress in Energy and Combustion Science* 2007;**34**:198–223.
8. Shahid EM, Jamal Y. A review of biodiesel as vehicular fuel. *Renewable and Sustainable Energy Reviews*. 2008;**12**:2484-94.
9. Mekhilef S, Siga S, Saidur R. A review on palm oil biodiesel as a source of renewable fuel. *Renewable and Sustainable Energy Reviews*. 2011;**15**:1937-49.
10. Song JVZ, Boehman AL. Comparison of the impact of intake oxygen enrichment and fuel oxygenation on diesel combustion and emissions. *Energy & Fuels*. 2004;**18**:1282-90.
11. ountalas GCM D T, Binder K B. Effect of exhaust gas recirculation (EGR) temperature for various EGR rates on heavy duty DI diesel performance and emissions. *Energy*. 2008;**33**:272-283.
12. Jacobs T AD, Filipi Z. The impact of exhaust gas recirculation on performance and emissions of a heavy-duty diesel engine. *SAE Paper* No 2003-01-1068, 2003.
13. Rajan KRS K. Effect of Exhaust Gas Recirculation (EGR) on the Performance and Emission Characteristics of Diesel Engine with Sunflower Oil Methyl Ester. *Jordan Journal of Mechanical and Industrial Engineering*. 2009;**3**:306 -11.



Biography

Dr. Rizalman Mamat is associate professor in Mechanical engineering department, University Malaysia Pahang, Pahang, Malaysia. He is expert in the fields of internal combustion engines and renewable energies.